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COMPRESSOR PROTECTION MODULE AND SYSTEM AND METHOD INCORPORATING SAME

BACKGROUND OF THE INVENTION

The invention relates to a compressor protection and control module and a system and method incorporating same.

Compressor maintenance and reliability are critical issues. In connection with reliability, a malfunctioning compressor can cause difficulties spanning from minor inconvenience to loss of valuable refrigerated product. Furthermore, compressors themselves are costly equipment and improper maintenance or operation can result in damage requiring expensive maintenance or replacement.

Systems and methods are known for limited, local control and protection of compressors. Such systems tend to focus on single parameters to provide for emergency action. Although this is helpful, such systems do not assist in identifying a potential problem before the compressor is incapacitated.

In light of the foregoing, it is clear that the need remains for improved compressor monitoring so as to avoid compressor shut downs, if possible, and minimize expense due to compressor repair/replacement, spoilage and the like.

Therefore, the primary objectives of the present invention are to (1) provide a module for protecting a compressor which detects trouble with the compressor before compressor failure, (2) provide a module that can control key operating and control functions based on monitored operating conditions and (3) provide such a module, and a system and method incorporating same, wherein preventive maintenance is facilitated.

Other objects and advantages of the present invention will appear hereinbelow.

SUMMARY OF THE INVENTION

In accordance with the present invention, the foregoing objects and advantages have been readily attained.

According to the invention, an apparatus for monitoring a compressor is provided, which comprises a plurality of sensor inputs for receiving input regarding operating parameters of a compressor; at least one control action output for sending a control action to said compressor; and a control member communicated with said plurality of sensor inputs and said control action output, said control member being adapted to analyze input from said plurality of sensor inputs to determine a control action based upon said input, and to send said control action to said at least one control action output.

A display may be provided and adapted to show sensor input values, control output and alarm status.

In further accordance with the present invention, a method is provided for monitoring a compressor, which method comprises the steps of obtaining input regarding a plurality of compressor operating parameters; feeding said input to a control member; analyzing said input with said control member to determine a control action based upon said input; and carrying out said control action on said compressor. A history of such control actions and sensor inputs may be stored for later retrieval and analysis.

Still further according to the invention, a compressor and control module system are provided, which comprises a control module comprising a plurality of sensor inputs; at least one control action output; and a control member communicated with said plurality of sensor inputs and said control action output, said control member being adapted to analyze input from said plurality of sensor inputs, to determine a control action based upon said input and to said control action to said at least one control action output.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of preferred embodiments of the present invention follows, with reference to the attached drawing, wherein Figure 1 schematically illustrates a functional block diagram of a compressor and module in accordance with the present invention.

DETAILED DESCRIPTION

In accordance with the present invention, a compressor protection module is provided which advantageously monitors a combination of compressor operating parameters and which is programmed to determine appropriate control actions based upon combinations of sensor input. Verification of the control function can also be accomplished by comparing the actual result to the expected result. The module of the present invention can thereby advantageously detect certain failure conditions before failure is imminent, thereby reducing maintenance and repair costs and avoiding potential damage to refrigerated product. The module can also be programmed to maintain application specific operating parameters as certain operating parameters and alarm setpoints can be adjusted within a limited range.

Turning now to Figure 1, a functional block diagram schematically illustrates a compressor and module in accordance with the present invention.

Figure 1 shows a compressor chassis 10 and a module 12 in accordance with the present invention. Module 12 includes a processor 14 and a plurality of sensor inputs for measuring compressor operating parameters. These inputs are preferably connected to various probes and transducers including a discharge thermistor probe 16 for measuring compressor discharge temperature, a return gas thermistor probe 18 for measuring return gas temperature or suction temperature, a suction pressure transducer 20 for measuring suction pressure, a

discharge pressure transducer 22 for measuring discharge pressure and an oil discharge pressure transducer 24 for measuring oil discharge pressure.

As shown in Figure 1, the sensor inputs may also advantageously include inputs 26 for power supply, compressor on/off signal and safety input signal, a crank case heater current transformer 28 which is preferably adapted to control and/or detect operation of the crank case heater of the compressor, an output 30 for liquid injection valve control and outputs 32, 34 for providing unloader control. Inputs for motor current and supply voltage could also be provided.

Processor 14 in accordance with the invention is advantageously communicated with each of these sensor inputs and has memory programmed with a series of commands adapted to evaluate different combinations of inputs from each sensor and thereby identify correct operating conditions, operating conditions indicating that the compressor is being improperly operated, operating conditions indicating that the compressor needs maintenance, operating conditions that indicate that the compressor must be operated under different conditions to avoid damage, and the like.

For example, control unit or processor 14 can advantageously be programmed so as to detect conditions such as a flooded start, liquid slugging, inadequate control of liquid injection volumes and liquid floodback. Each of these conditions can be inferred from different combinations of input from the sensor inputs, which will then allow for appropriate control actions to be taken.

Module 12 of the present invention can also advantageously be programmed to maintain a given operating condition and will control the compressor in order to maintain the programmed operating parameters. For example in refrigeration applications the compressor is typically controlled to maintain the suction

pressure within a given range. By monitoring the suction pressure, module 12 can be programmed to start and stop the compressor and operate the unloaders such that the desired suction pressure is maintained.

The various control actions that may be desirable, along with appropriate input value combinations for using such control actions, are stored in memory in module 12 for use in evaluating actual input and selecting a suitable control action for the compressor.

In further accordance with the present invention, module 12 advantageously is provided having an interface port 36 adapted for connection with communication capability, for example through CCN/LON or other communication network. This advantageously allows for remote access from and to module 12 so that information can be obtained from module 12 by personnel located at a remote location, and information can be automatically sent by module 12 to a remote location, as dictated by control actions corresponding to combinations of input from the sensor inputs. The communications can also be used to send commands to the module such as on/off control, unloading control and the modification of adjustable operating parameters. This communication can be by dedicated or shared telephone access, for example using a modem, or wireless access, or through any other manner known to persons of ordinary skill in the art.

Module 12 in accordance with the present invention further preferably includes a human interface 38 which may advantageously be a display member for indicating various information to a user, such as current operating status, detected fault conditions, and the like. The display can also be utilized to modify adjustable operating parameters such as unloading and liquid injection setpoints and application

specific warning parameters such as high limits for return gas temperature and discharge temperature.

Still referring to Figure 1, module 12 may advantageously be communicated with a system control box 40 such that commands issued by processor 14 can be enacted on the compressor, for example to change operating speed, turn off power, control crankcase heater operation, and the like,

Module 12 in accordance with the present invention advantageously provides for two forms of compressor protection, specifically, immediate and prognostic protection. Immediate protection is provided for combinations of input indicating a failure is occurring or likely to occur, and the compressor can be immediately shut down or other action taken. Prognostic protection is provided for combinations of sensor input that indicate impending failure or degradation of compressor performance, and suitable action may include adjusting the compressor operation accordingly and issuance of a warning to the user and/or maintenance personnel that compressor maintenance is required.

As set forth above, it is particularly advantageous in accordance with the present invention to program module 12 and processor 14 to detect certain types of conditions based upon input from the different compressor sensors. It is preferred that the input sensors include input as to compressor suction pressure, compressor suction temperature, compressor discharge pressure, compressor discharge temperature and oil pressure. It is important to note that the entering (suction pressure and temperature) and leaving (discharge pressure and temperature) refrigerant conditions are measured for each individual compressor. With these factors, flooded starts, liquid slugging and liquid floodback can be detected, and appropriate action taken. With additional sensor input as to the liquid injection set point, module 12 and processor 14 can be adapted to detect

inadequate control of liquid injection as well, and take appropriate action.

Thus, module 12 in accordance with the invention advantageously allows protection of the compressor using local sensors, preferably positioned within about one foot of the compressor, which gather information for processing by module 12 to take action dictated by programming in module 12 and also to allow communication from remote locations, for example a monitoring station at a completely different building, site or location, as desired, so as to provide effective protection of the compressor and, when applicable, products preserved by operation of the compressor.

FLOODED START DETECTION

Liquid refrigerant will often return to a compressor during an off cycle. Starting the compressor when it is filled with liquid refrigerant can cause severe damage to the compressor including compressor failure. In accordance with the present invention, processor 14 is advantageously adapted to detect a flooded start, as well as the severity of the flooded start, and to either warn the user or shut down the compressor, as appropriate.

By examining the suction temperature, suction pressure, discharge pressure, discharge temperature and oil pressure variations during the startup of the compressor, processor 14 can differentiate a flooded start as compared to a normal compressor start, as well as the severity of same, and take an appropriate control action.

LIQUID SLUGGING

Liquid slugging is a major cause of compressor failure. A refrigerant compressor is designed to compress vapor refrigerant and pump the refrigerant through the refrigeration/air

conditioning system. Any liquid (i.e. non-compressible fluid), which is returned to the compressor, even in small quantities, will stress the compressor and can, in larger quantities, result in compressor damage. By examining the suction temperature, suction pressure, discharge pressure, discharge temperature and oil pressure variations during a period of liquid slugging, processor 14 can detect such slugging and, depending upon the severity of same, take a control action including sending a warning to a user or maintenance personnel, or shut down the compressor, or both.

LIQUID INJECTION CONTROL

Inadequate control of liquid injection can result in inefficient compressor operation and possible compressor failure. Certain high compression ratio operating conditions require liquid refrigerant to be injected in the compressor suction stream in order to maintain the compressor discharge temperature within acceptable operating limits. In accordance with the present invention, the amount of liquid injection is optimized based on energy efficiency and temperature reliability requirements, and operation of the liquid injection valve is confirmed by comparing reduction in discharge temperature to an expected reduction in discharge temperature. Providing good liquid control optimizes compressor energy efficiency and reliability.

In accordance with the present invention, the opening of the liquid injection valve (output on module 12) is controlled based on the liquid injection set point and the measured compressor discharge temperature. If the discharge temperature rises above the set point, the valve opens until the discharge temperature drops below the set point. By evaluating the response of the valve (i.e., the measured reduction in discharge temperature) the module can determine if the valve is working

properly by comparing the actual reduction in discharge temperature to the expected reduction in discharge temperature.

LIQUID FLOODBACK

Liquid floodback is a major cause of compressor failure. Liquid refrigerant returned to the compressor is one of the leading causes of compressor failure, and module 12 in accordance with the present invention is advantageously adapted to determine if, and to what extent, liquid refrigerant is entering the compressor.

Processor 14 advantageously is adapted to calculate or determine suction superheat to determine if liquid refrigerant is entering the compressor. If excessive liquid refrigerant is returned to the compressor, it will extract heat from the refrigerant stream when it boils off thus resulting in lower operating temperatures. An expected compressor discharge temperature is calculated and compared to the measured actual discharge temperature to determine the extent of the floodback.

The module is programmed with refrigerant properties such that it can calculate characteristics of the refrigerant type in use. With this information, processor 14 calculates a saturation temperature based upon refrigerant property tables and suction pressure. The suction superheat is then determined by subtracting the saturation temperature from the suction temperature. If the suction superheat is below a warning threshold, the user is warned of a floodback condition.

The expected discharge temperature is calculated as a function of pressure ratio, suction temperature, compression coefficient and compressor type. This is based upon the discovery that evaporation of liquid refrigerant returned to the compressor will suppress the discharge temperature. The difference between the expected discharge temperature and actual

discharge temperature is proportional to the amount of liquid refrigerant returned to the compressor.

Although the foregoing lists four particularly preferably conditions which module 12 in accordance with the present invention is adapted to detect, a further listing of conditions corresponding to different sensor input and appropriate control actions corresponding to same is provided in Table 1 below.

TABLE 1

Failure Mode or Symptom	Description	Possible Control Action(s)	Sensor(s) Required
High Pressure Protection	High discharge pressure at the discharge side of the compressor.	Turn off the compressor if the discharge pressure exceeds a threshold value.	Discharge Pressure
Compressor Overheating	Compressor Overheating is a major cause of compressor failures. It has the following potential causes: - broken discharge valve - low refrigerant charge - liquid injection failure - cylinder head cooling fan failure	Turn off the compressor if the discharge temperature exceeds a threshold value. Unload Compressor.	Discharge Temperature
Low Oil Pressure	Low oil pressure is also a major cause of compressor failures as it results in a lack of lubrication. It has the following potential causes: - liquid refrigerant in crankcase - high compressor wear - bad oil pump.	Turn the compressor off if inadequate net oil pressure is developed.	Oil Pressure Suction Pressure * net oil pressure calculated as oil pressure - suction pressure
High Return Gas Temperature	High suction gas temperatures returned to the compressor can result in inadequate motor cooling and compressor overheating.	Warn user of high suction temperatures.	Suction gas temperature
High Compressor Cycles	High compressor cycling is generally an indication of a bad system design or refrigerant control problems. High compressor cycles can lead to premature compressor failures.	Limit compressor cycling by including a minimum off time. Warn user of high compressor cycles.	Run/Stop Signal
Low Refrigerant Charge	Low refrigerant charge can result in high motor and discharge temperatures and freeze up of the evaporator.	Turn compressor off during low suction pressures or high discharge temperatures.	Suction Pressure Discharge Temperature
Motor Overheating	The motor can overheat due to inadequate refrigerant cooling or running the compressor above its design limits.	Turn the compressor off at high discharge temperatures.	Discharge Temperature
Liquid Refrigerant Floodback	Liquid refrigerant returned to the compressor in the suction gas stream. Generally caused by excessive refrigerant feed through the expansion valve.	Warn user when suction/discharge superheat is low. Shut down compressor with excessive floodback.	Suction Temperature Suction Pressure Discharge Pressure Discharge Temperature
Liquid Slugging	Relatively large amounts of liquid (refrigerant and/or oil) returned to the compressor in a short period of time.	Turn on warning light or alarm. Record fault in memory. Shut down compressor if excessive	Suction Temperature Suction Pressure Discharge Pressure Discharge Temperature
Flooded Start	When a large volume of refrigerant accumulates in the crankcase or oil sump at shut down it dilutes oil. This can in turn lead to a lack of compressor lubrication.	Turn on crankcase heater. Warn user of alarm. Turn compressor off if excessive.	Suction Temperature Suction Pressure Discharge Pressure Discharge Temperature

As can be seen, a substantial list of potential failure modes or symptoms and corresponding control actions are available and can be incorporated into the programming of module 12 in accordance with the present invention. In some instances, failures can be determined using different sensors. For example, as shown in Table 1, refrigerant floodback can be determined from input obtained from four different sensor combinations.

It is anticipated that the module in accordance with the present invention can advantageously be used to reduce failure rate of a large number of compressor parts, including for example main bearings, crankshaft, head gasket, discharge valve, suction valve, motor and connecting rods, and the like.

In order to perform the desired operations in accordance with the present invention, module 12 and processor 14 are advantageously provided with control functions utilizing triac outputs, specifically, triac outputs for CR1, CR2, liquid injection, crankcase heater on/off, alarm, unloader 1 and unloader 2.

Module 12 may advantageously be provided having non-volatile memory which can be accessed from remote locations as identified above, and is advantageously adapted to save operational data so as to assist in diagnosing problems. For example, it is anticipated that 8K of non-volatile memory would be suitable for such purpose, although different amounts of memory may be desired.

Fault conditions are also preferably saved in such memory for later retrieval.

Human interface 38 in accordance with the present invention may advantageously consist of any known devices for communicating information to the user, such as LED digits, LED's and buttons. Such an interface allows a user to monitor compressor operational status, to monitor compressor output

status, to monitor compressor input values, and to setup configuration values. Human interface 38 may advantageously be directly driven by module 12, and processor 14 of same, and may have any combination of display elements suitable for conveying the desired information, for example, three 8-segment LED's, three push buttons, and eighteen individual LED's could be provided for conveying such information.

Human interface 38 may further include a display listing various faults, for example, over current, high pressure, low pressure, oil pressure, floodback, motor temperature and crankcase heater malfunction. Such listings can be adapted to display one or more items as desired, for example, with LED's next to each item on the list, or in other manners well known to a person of ordinary skill in the art, and are communicated with processor 14 such that control actions selected by processor 14 can include commands for operating interface 38 so as to provide appropriate displays as well.

In accordance with the foregoing, it should readily be appreciated that a module has been provided which can be used with compressors of varying types, for example screw compressors, reciprocating compressors, scroll compressors, rotary compressors and others, so as to detect impending failure and take appropriate action. The module is particularly advantageous as compared to conventional systems in that actions are taken based upon combinations of input from different portions of the compressor, and remote actions are enabled. This advantageously allows for both prognostic and immediate protection of the compressor.

It is to be understood that the invention is not limited to the illustrations described and shown herein, which are deemed to be merely illustrative of the best modes of carrying out the invention, and which are susceptible of modification of form, size, arrangement of parts and details of operation. The invention rather is intended to encompass all such modifications which are within its spirit and scope as defined by the claims.